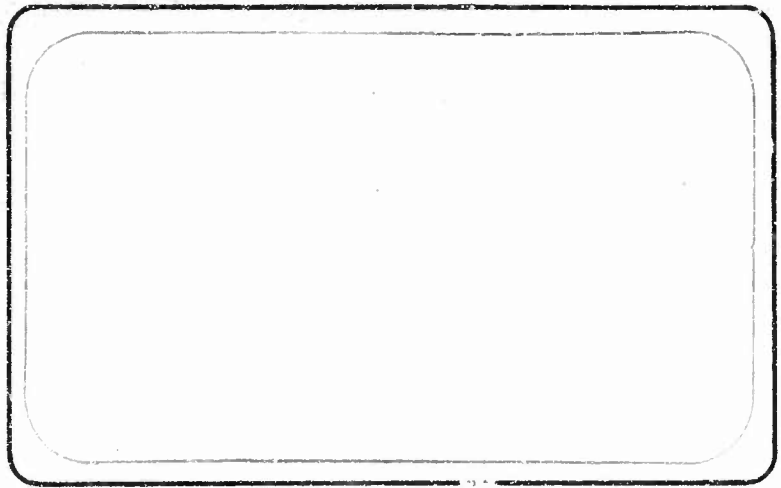




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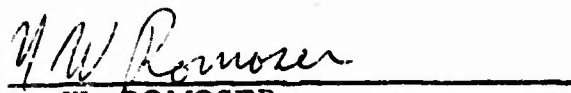
A Black-Field Illuminated
Shipboard Clock

Assignment 62 104
MEL R&D Report 391/66
March 1967

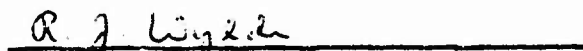
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ABSTRACT

An illuminated, bulkhead-mounting clock has been developed that has outstanding conspicuity in the low-level luminous environments of combat information centers and darkened radar and sonar spaces. This development applies the "Black-Field" (photoluminescent) illumination technique to effect a unique presentation of hour, minute, and sweep-second hands as well as graduations and numerals in high contrast against a virtually "black" background.

Although the lamp that feeds the optical system is in line-of-sight, it cannot be seen. The dial is of the "see thru" type and consists of numerals and graduations processed in the inner surface of the black-light-absorbing "dial-window." The design features of the initial lot of preprototype clocks are described.

The applicability of this technique to the illumination of other military displays is noted and it is recommended that a program be undertaken to develop near ultraviolet transmitting (almost visually opaque) plastic filters to replace glass where structural or manufacturing considerations make its use undesirable.

ADMINISTRATIVE INFORMATION

Reference (a) included authorization for MEL to proceed with the design and construction of a small lot of illuminated bulkhead-mounting clocks for use in the low levels of illumination prevalent in combat information centers. This work was continued under reference (b) and became part of MEL Assignment 62 104.

The first sample MEL Black-Field illuminated clock was delivered by hand to BUSHIPS (Code 665J) on 2 March 1966 under reference (c). The remainder of this "preprototype" trial lot has been made available for shipment to designated ships for Fleet evaluation. Each package contains a copy of the Installation Notes, Appendix A.

ACKNOWLEDGEMENTS

The cooperation of the following individuals is acknowledged. Without their interest and cooperation the MEL clock could not have been completed.

- Dr. C. E. Leiberknight, Kopp Glass Works, Pittsburg, Pennsylvania, for custom formulation and molding of tempered glass filter disks.
- M. A. Mortensen and his associates, of General Electric Lamp Research Laboratories, Nela Park, Cleveland, Ohio, for information on spectral distribution of black-light phosphor and suggestions on a three-luminance-level fluorescent ballast circuit.
- Bob Brumfield and associates of Switzer Brothers, Day-Glo Coating Laboratory, Cleveland, Ohio, for advice and trial formulations of Day-Glo photoluminescent coating materials.
- Stewart Sease and William Cunningham, Rohm and Haas Color Laboratory, Bristol, Pennsylvania, for colored plastic formulations.
- John Hoxie, Corning Glass Works, Corning, New York, for many informative discussions on state-of-the-art colored signal glassware technology.
- R. L. Booker of MEL for spectrophotometric transmittance determinations on many glass and plastic formulations.

ADMINISTRATIVE REFERENCES

- (a) BUSHIPS ltr NP/3 ser 665-1874 of 31 Aug 1964
- (b) BUSHIPS ltr ser 320-085 of 16 Jun 1965
- (c) MEL ltr NP/9870 (620 JTM) of 14 Mar 1966
- (d) Mil Spec MIL-C-2339 (SHIPS) "Clock, Electric, Internally-Illuminated, Wall-mounted, "dated 27 Jul 1962 with Amendment 2, 9 Oct 1963
- (e) U. S. Patent 3, 270, 201 of 30 Aug 1966

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A BLACK-FIELD ILLUMINATED SHIPBOARD CLOCK

1.0 INTRODUCTION

1.1 Background. Luminous environments of darkness, almost complete darkness, or of a low level of "dark adaptation red" either occur naturally or are deliberately provided in cathode-ray viewing areas of many military and space command, control, or monitoring stations. In the Navy, controlled low ambient illumination is provided in "live" radar, sonar, and combat defense centers and in submarine control rooms. In addition to making target detections and other visually supported judgments through use of primary cathode ray tube (CRT) viewing screens, every operator must at times have recourse to illuminated controls and auxiliary displays.

Auxiliary displays (such as clocks placed to be viewed by a number of people or a single person from a number of vantage points) must not aggravate the problem of unwanted light. Regardless of the color of light that emanates from it, the auxiliary display must not "floodlight" the space and thus raise the ambient level significantly. This ambient is a most significant parameter for the establishment of the operator's threshold for low-luminance-target-detection. Auxiliary displays, furthermore, must be capable of being dimmed over a wide range to remain tolerable to the operator during the interval over which his adaptation to low ambient levels progresses.

1.2 Problem. Control- and monitoring-station indicating instruments of some (small area) categories have benefited greatly from internal-illumination techniques developed for stringent requirements of ship's bridge, submarine and aircraft cockpit, and crew station instruments. Most of these techniques readily illuminate scales, numerals, and pointers in high luminance contrast against a Black-Field. The illumination of pointers, though, is the prime problem even with the most successful internal illumination techniques. By comparison, the illumination of fixed dials and scales is easy. Difficulties with pointer illumination increase exponentially with size and often there is no feasible solution.

Specifically, there has been no really satisfactory means of illuminating the hour, minute, and sweep-second hands of a 12-inch clock. There are a number of designs of commercial "advertising-clocks" that present hands, numerals, and legends in silhouette against a white field by day and against a backlighted (translucent) "full-moon" luminous field at night.

Such designs obviously offer no solution inasmuch as they broadcast an excessive amount of noninformation-conveying light that illuminates the whole work area. Many retail business establishments prize such clocks as "night-lights" for just this reason.

It is almost a design paradox then that the Black-Field illumination technique to be described in this report actually employs the same general relationship of lamp and dial as do the full-moon advertising clocks. Thus, it is virtually a back-lighting technique. However, Black-Field illumination results in contrast reversal - the dial numerals and hands glow brightly while the background, through which the exciting "light" passes, appears opaque, and the lamp not only is not seen, but its location is not suspected. The technique does not require the use of high voltages or frequencies or electrical connections to any of the illuminated display elements. Instead, it relies on exploitation of the complimentary characteristics of previously known optical components. The technique is as readily applied to display areas of several square feet as it is to smaller areas. In fact, the currently available lamp sizes favor square feet rather than square inches as display sizes. Power requirements are in line with those of full-moon displays, 30 watts per square foot being a typical value for advertising applications, covered by reference (e), or as an estimate for power consumption of proposed military displays when they are operated at maximum luminance levels.

2.0 THE APPLICATION OF BLACK-FIELD ILLUMINATION

The MEL Black-Field illuminated clock is shown assembled in Figure 1 and (as illuminated in darkness) in Figure 2. It was designed specifically to be used in the darkened combat information center (CIC) spaces aboard naval aircraft carriers. Its design is developmental, but only minor changes will be required to convert it to a completely "engineered" Navy production design.

2.1 Objectives. General design and performance objectives set forth for this clock were: (a) a nominal 12-inch face; (b) a means of selecting several working levels of luminance; (c) a wide observational angle; (d) illumination of the sweep-second hand as well as the hour and minute hands, dial markings, and numerals; (e) a bulk-head mounting metal enclosure that would offer optimum practical protection to the clock components; (f) outside resetting of hands without removal of clock from bulkhead; and (g) a physical assembly that would maintain structural integrity and prevent internal clock parts or broken glass from being expelled from the enclosure to become secondary projectiles under the conditions simulated by 2000 foot-pound high intensity shock test procedures. Some other

guidance was taken from the specification, reference (d), but much of that specification is specific solely to electroluminescent techniques and hence inapplicable.

2.2 Construction. Figure 3 reveals that the light source is a "circline" fluorescent lamp. A (115-volt, 60-cycle) synchronous clock motor may also be seen mounted on a "spider" attached to the center of a concave-convex, circular, glass optical filter that has a thick, flat mounting flange. Concealed from view are lamp ballast, resistors and a "3-level" dimming switch. The graduations for minutes and hours and the numerals are on the inner surface of a protective (plastic) "dial-window." The plastic hour, minute, and sweep-second hands that are conventionally mounted on the three concentric shafts of the clock motor are shown in Figures 1 and 2.

The critical components of this clock are described below.

2.2.1 A 22-Watt Black Light Circline Lamp. This lamp contains a phosphor that has a maximized output of photoexciting energy (near ultraviolet, violet, and blue) but a minimum of other visible light, particularly in the red end of the spectrum. (The ready availability of such black-light phosphor circline lamps is the result of their widespread use to attract insects to the intakes of fan-type insect traps.)

2.2.2 A Custom-Formulated, Tempered, Molded, Filter-Glass Disk. This component has sharp spectral cutoff characteristics. It transmits a maximum of the desired near-ultraviolet and other photoexciting energy and essentially none of the visible spectrum other than deep-blue-violet. Its concave-convex form has several purposes: it facilitates manufacture involving molding and tempering techniques and, because it is structurally superior under shock, the clock-motor movement may be mounted on it through the use of a nonshadowing spider. The convex surface has been given a special out inexpensive low-reflection treatment to virtually eliminate specular reflection. In the untreated form this filter-glass disk is identified as Kopp Glass (Pittsburgh, Pennsylvania) No. CG-1206, 81 UV, 12-inch diameter with 3/4-inch hole.

The hole in the center was produced by core-drilling a biscuit from a thin, rounded-edge, central section of the molded disk before it was tempered. This hole is large enough to provide clearance for a plastic bushing which isolates the stainless steel clock-movement mounting bushing of the nonshadowing spider. Mounting the mechanism on the glass rather than the enclosure guards against disastrous relative motion under shock, permits

minimum shaft length, and provides a positive means of maintaining shaft and clock-hand alignment following nondestructive shocks suffered in operation by the clock.

2.2.3 A Plastic Dial Window. This window is not only protective but has several other functions: It provides a support for the graphics of the clock face, and it serves as a sharp cutoff, pale-yellow, optical absorption filter. It was vacuum formed from 1/16-inch-thick Rohm and Haas (Philadelphia, Pennsylvania) No. 2208 pale-yellow Plexiglas sheet stock. The window, however, does not have to be vacuum formed. It does not have to be of acrylic material, either, but just any pale-yellow plastic would not serve. The plastic must have carefully controlled spectral transmittance characteristics over the entire visible and near ultraviolet spectrum--a high transmittance over the red-amber-green portions and essentially zero in the photoexciting (deep blue, violet, and near ultraviolet) zones. An observer attempting to look through both of these filters at any ordinary light source finds that he is faced with an opaque or almost completely opaque combination. Actually, it is essential only that the superimposed filters be opaque in conjunction with the light emitted by a black light phosphor fluorescent lamp.

2.2.4 Photoluminescence. The dial markings and the coatings on the clock hands are of "photoluminescent" material. Materials of the photoluminescent category absorb near ultraviolet or blue light and re-emit visible light of longer wavelengths. They may be organic or inorganic. The organic photoluminescent pigments have been highly developed in recent years and are widely available in a variety of color formulations. The formulation of pigment and vehicle used for the clock numerals was especially compounded for application to plastics by the silk-screen process. The vacuum forming of the silk-screened sheets was a subsequent process. This involved heating the sheets to forming temperature, a requirement that had to be given consideration in the formulation of the coating.

The hour and minute hands have been fabricated from transparent polycarbonate sheet stock. The rear surfaces and edges of these hands have been sprayed with a suitable photoluminescent spraying formulation. The long thin sweep-second hand is similarly constructed, but in practice, because of its shape, is sprayed on all surfaces.

3.0 GENERAL THEORY OF BLACK-FIELD ILLUMINATION

Following the implications of the component descriptions just given, the theory of Black-Field illumination is almost evident - at least insofar as it is applied to the MEL clock.

3.1 Energy Source. First, a source of radiant energy - in this instance the circline black-light fluorescent lamp - is housed in an enclosure with an optical filter that is viewed as the background of the clock dial and hands. The front (obverse) surface of this filter has been sandblasted and subsequently treated with an acrylic optically "flatting" formulation to provide diffusion and destroy the original, highly specular, molded surface. This creates a new obverse surface which has a practical minimum of specular reflectance. Assembled over this filter (but with a useful intervening air space, nominally an inch) is a second optical filter which has been vacuum formed from a pale-yellow plastic sheet. In working out the necessary spectral transmittance characteristics of these two (glass and plastic) filters, special consideration was given to the spectral distribution of the radiant energy of the lamp and the spectral response characteristics of the human eye. The result is an optimized combination which presents a virtually opaque visual field to the observer although he is facing an area that is usefully "back-illuminated."

If now a nonphotoluminescent, opaque, white object is placed in the space between the filters, it can be seen by the observer in daylight or artificial light but not in darkness. However, when photoluminescent numerals, clock hands, or the like are installed in this space they behave quite differently. They absorb the unseen (invisible) radiation and reradiate considerable visible energy. Most of the reradiated energy is in the zones of the visual spectrum that are capable of being transmitted through the light-yellow protective filter. The result is a somewhat mysterious glow of the photoluminescent material. The choice of color in photoluminescent materials is restricted by the minus-blue spectral cutoff characteristics of the plastic filter.

The cooperating functions of the filters are evident by visualizing the effect that would result if the pale-yellow filter were to be removed. The clock hands would still be rear-excited and would convert invisible energy to visible light, but the observer's vision would "penetrate" the glass filter at least to the degree that he would be acutely aware of the lamp and the fact that it projects an objectionable amount of light and other energy in his direction. The clock hands would be as bright, but their high luminances would not be appreciated by the observer because the near-ultraviolet energy component would cause fluorescence phenomena in his eyes, giving him the sensation of viewing the display through a luminous haze. With the interposition of the pale-yellow (minus ultraviolet and blue) plastic filter, however, all of the unused exciting energy is absorbed, no near-ultraviolet light reaches him, his eyes do not fluoresce, and the visual contrast between the photoluminescent hands and the background is very great.

Even strong sunlight cannot penetrate the plastic and glass filter combination and be reflected back to the observer through the filters to reveal the lamps or mechanism in the rear compartment of the enclosure. Depending on choice of photoluminescent materials, the dial markings and hands may be yellow, green, or red. It is possible to enhance the daylight reflectivity of the dial markings by silk screening a translucent white coating on the dial window prior to silk screening the photoluminescent material, but this results in a reduction of luminance in darkness.

In summary then, Black-Field illumination relies on the basic concept of a transparent-walled, one-way, light trap containing useful photoluminescent markings that can be observed through one wall and excited through the other without betrayal of the source of exciting radiation.

4.0 PERFORMANCE OF ILLUMINATED CLOCK

The average initial luminances of the hands and markings of the clock described are approximately 4.9 and 5.9 footlamberts, respectively. The luminance selector switch shown diagrammatically in Appendix A permits reduction to levels of approximately 1/7 and 1/40 of these values. The maximum level is thus considerably higher than is currently obtainable from practical red electroluminescent or radioisotope sources. The luminance of this clock will of course diminish somewhat rapidly for the first 100 hours of fluorescent lamp operation as a result of lamp-phosphor ageing. After this period, it should slowly diminish over the remainder of the lamp's life. Earlier developmental models of this clock using circline lamp(or high voltage cold cathode lamp) excitation have been in operation for several years without failure of the photoluminescent material. Inasmuch as this material is highly protected by the ultraviolet absorption characteristics of the outer clock filter, it appears that the clock's markings would have a long life even if the clock were to be exposed to sunlight. In any event, the relative cost of components is such that it would be economical to replace all photoluminescent dials and hands at, say, every fifth or sixth lamp replacement should the conditions of use demand that near-maximum luminance levels be maintained.

5.0 DISCUSSION

Some implications of the Black-Field illumination technique can be visualized by projecting the design concept of the clock described. This clock, incidentally, could have been made with a sharp cutoff red or green plastic window had it been intended for use where severe dark adaptation

red lighting or photographic darkroom specifications prevail. The MEL clock has demonstrated something that has not been practical with electroluminescent techniques--that is the ability to illuminate the entirety of a long thin sweep-second hand.

Through the use of study models, this technique has been found to be useful for the otherwise difficult task of adequately illuminating the arched "bubble-glasses" of submarine clinometers and a proposed computer-compatible target-position plotting board. Some of the figures of reference (e) (under which the Government has a limited royalty-free license) suggest such applications.

6.0 STATE-OF-THE-ART SUMMARY

The MEL clock covered by this report represents an economical stopping point of development that is just short of a production design. Considerable attention was given nevertheless to production materials and processes in order to avoid design pitfalls in eventual procurement under contract. For example, while Rohm and Haas No. 2208 acrylic sheet was used for the vacuum-formed dial-window, it has been established that there are several acrylic colored molding powders that will impart a suitable spectral transmittance to an injection-molded dial-window. For 1/8-inch thicknesses, Rohm and Haas Colors 28001 or 688 are suggested equivalents. It is possible that greater impact strength will be obtained from the more expensive injection-molding grades of polycarbonate resins. Because colored sheet stocks of polycarbonate plastics are not as readily available, no color investigation was run on them.

In production, the clock hands should be injection-molded, of polycarbonate. They should have suitable metal, clock-motor-engaging inserts which may be molded in place or (perhaps preferably) inserted by ultrasonic penetration techniques. The hands of the MEL-constructed clocks were cut from 1/16-inch General Electric Lexan polycarbonate sheet stock. They were then heated to softening temperature in air, bent to the shape of the form, and allowed to cool in the form. Their metal inserts were mechanically retained in the hubs by crimping.

The near ultraviolet-transmitting glass filter used in the clocks is thought to be suitable for production models in geometrical form and to possess the practical optimum of spectral energy transmittance characteristics. Duplicates are currently available from the same melt, under part No. CG 1206, from Kopp Glass. Nominally this is a "tempered"

product but its three-dimensional shape and the essential hole in its center placed limits on the tempering process. Consequently, it will not break up into a myriad of tiny cubes as do some automotive safety glasses, but compared to nontempered glass will exhibit superior strength.

Through use of the Black-Field illumination technique, it is possible to solve several categories of visual display illumination problems in applications ranging from ships and submarine bubble-in-glass clinometers to computer-compatible X-Y plotting boards. Some applications such as the MEL clock will have a volume potential sufficient to justify the design of custom molds and the formulation of custom glass melts. For other, short-run applications, ultraviolet filters of plastic would be much more suitable.

As previously stated, the Black-Field technique is not area-limited in the large-area direction and its small-area limits are largely the result of lack of suitable black light sources. Special multiple instrument arrays analogous to marine or automotive speedometer-dash assemblies are practical, however, provided the individual instruments can be arranged to share lamps and filters. Available lamps will permit individual instruments to be as small as perhaps 6-inches square. Displays having areas of 10 square feet or more are being produced by industry and this may lead to the commercial availability of high-grade, quality-controlled, sheet glass filters that will be of interest for military instrument applications. Such availability, however, would not void the need for high strength molded glass (or plastic) filters as in the clock.

7.0 RECOMMENDATIONS

It is recommended that:

- A new specification, similar to Military Specification, MIL-C-2339 (SHIPS), but prescribing Black-Field illumination instead of electroluminescent illumination be prepared and issued as soon as possible. This specification and its early revisions should reflect the results of service experience with the initial lot of MEL handmade preprototype clocks as data become available. It should also specify the complete illumination of the sweep-second hand.

- Inasmuch as this development could influence procurement for many years, a statistically significant number of production design Black-Field illuminated clocks be procured under contract and placed in ship and shore installations for more comprehensive user evaluation.

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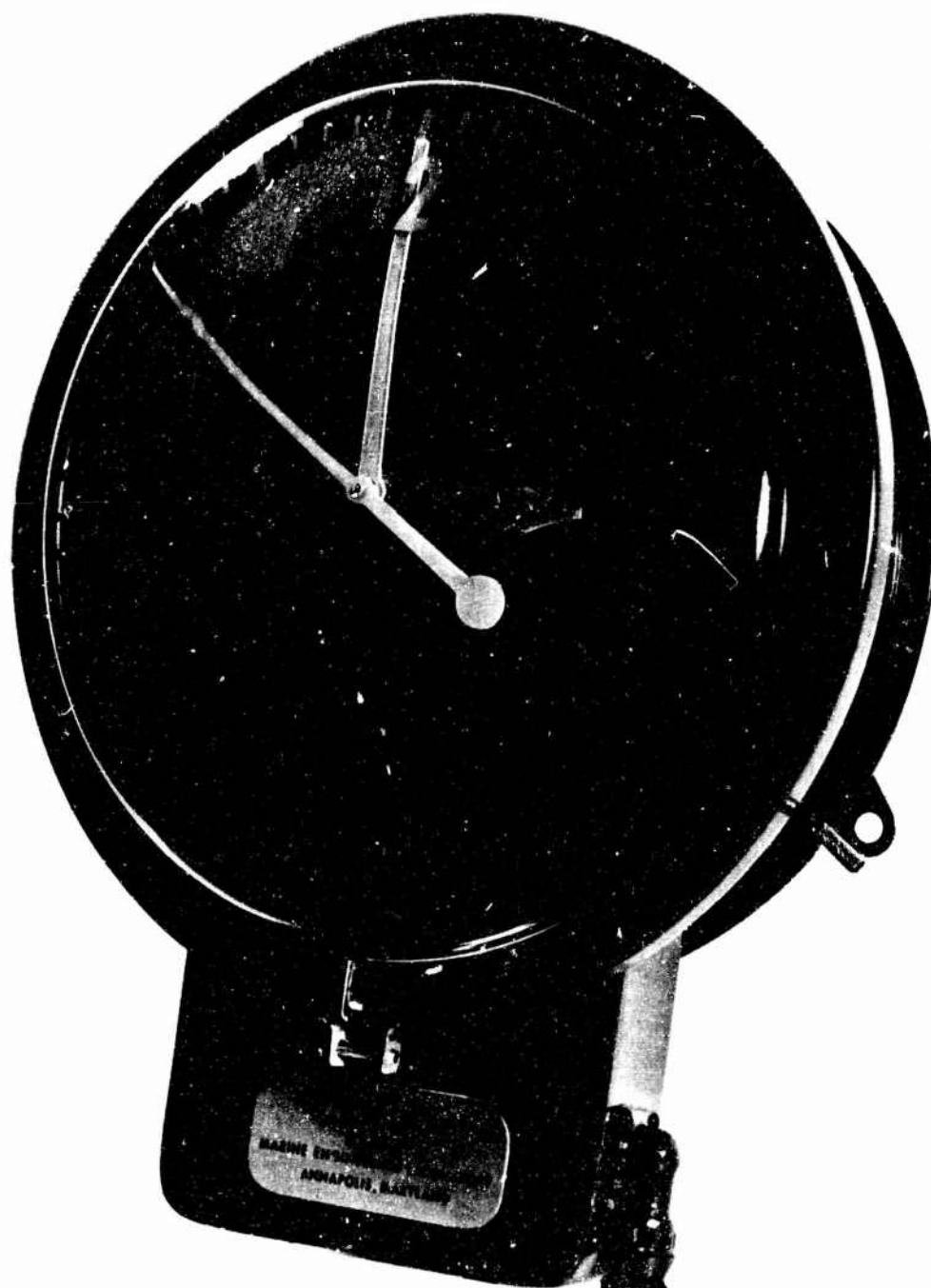


Figure 1

Black-Field Illuminated Clock Completely Assembled

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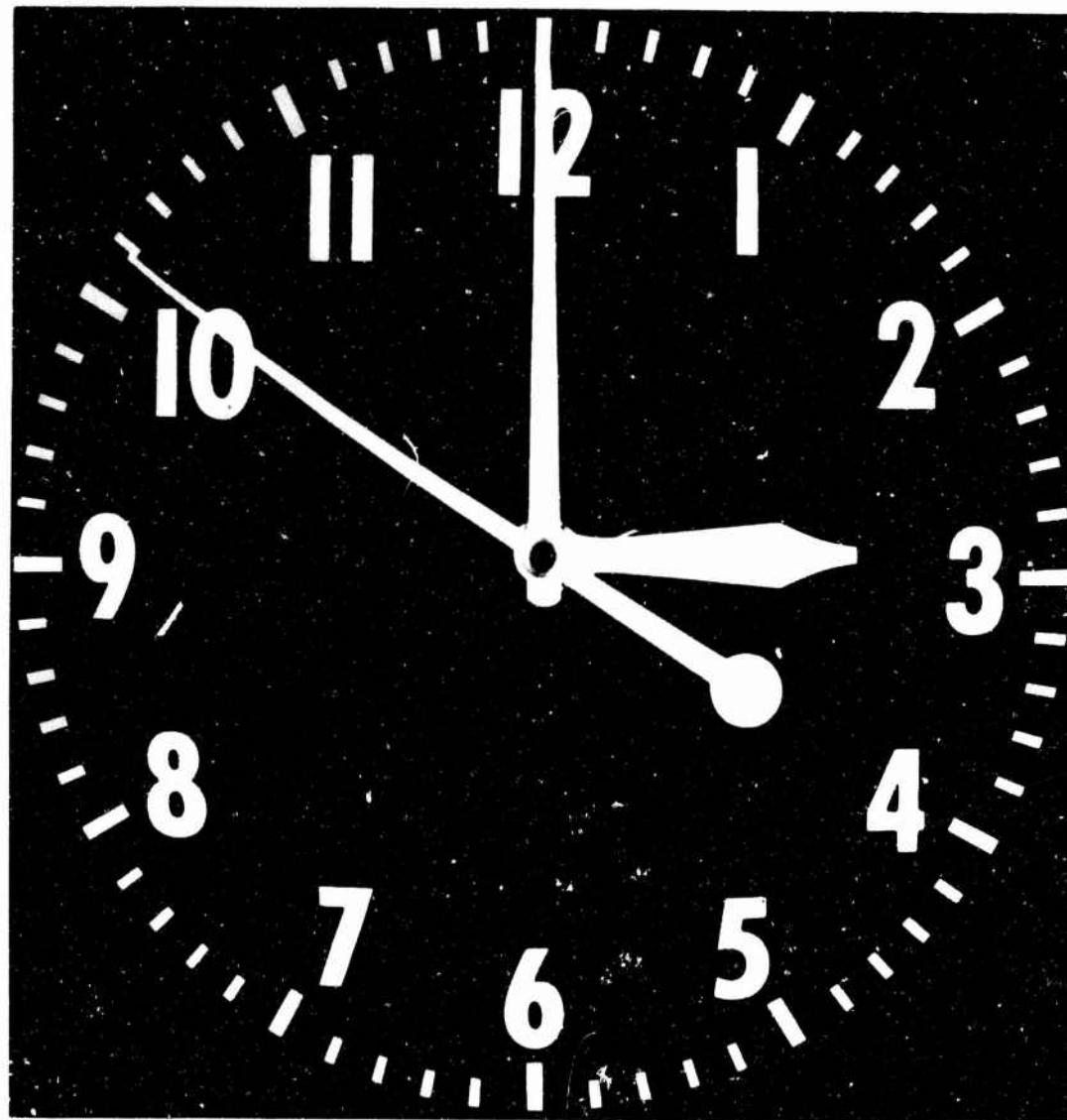


Figure 2

Black-Field Illuminated Clock as Viewed in Darkness

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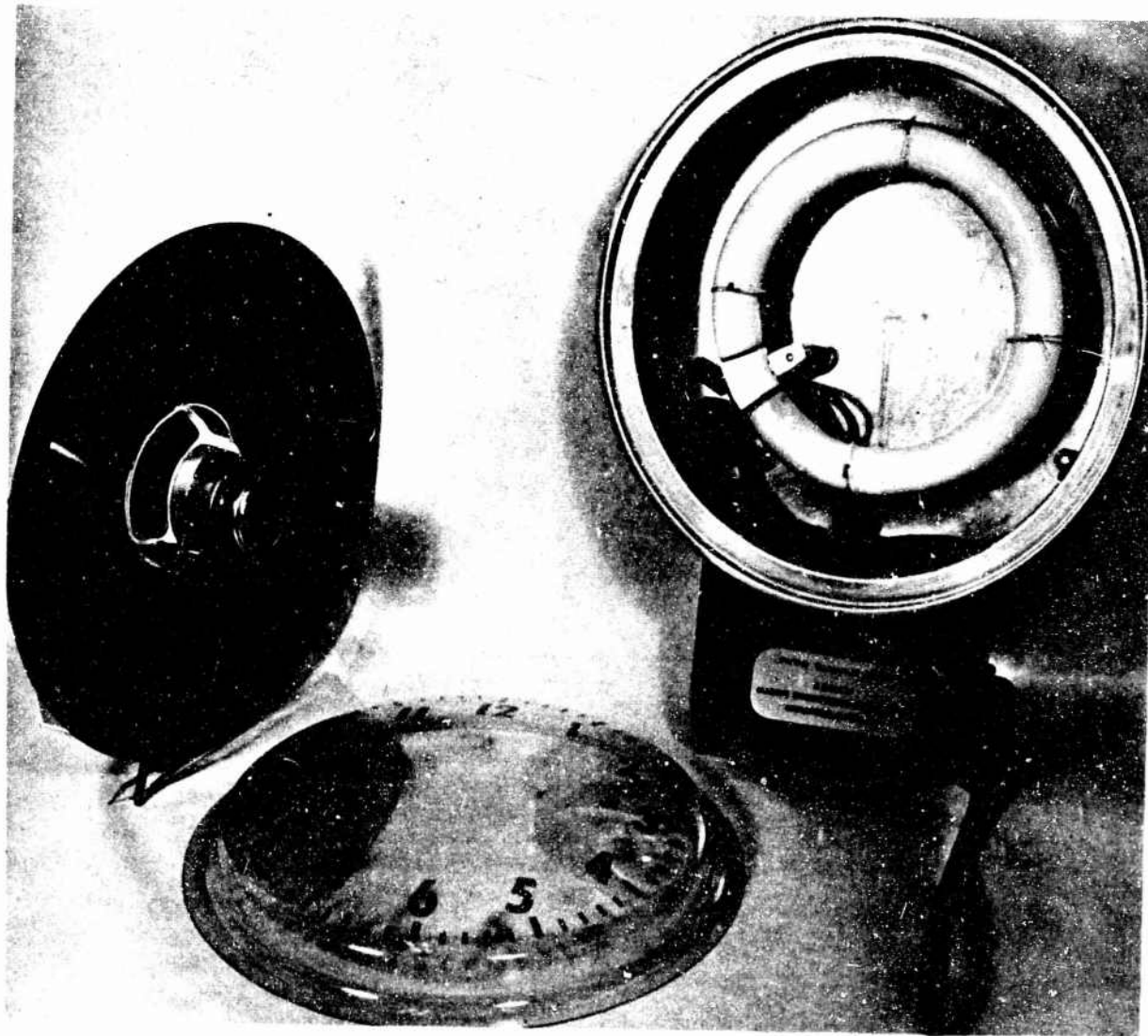


Figure 3

Partial Disassembly, Showing Lamp,
Ultraviolet Filter, and Dial Window

Appendix A

Installation and Lamp Replacement Notes on MEL
Black-Field Illuminated Clock

Background Information

This clock was developed and is being evaluated under the sponsorship of NAVSEC (Code 6665). It is particularly designed for use in CIC and other low ambient illumination spaces.

The clock is one of a small lot of hand-made developmental models - not a production design. The design will be refined for manufacturing convenience and economy if the results of the shipboard evaluation tests are satisfactory.

Unlike the electroluminescent clocks that are now in use on some ships, this clock does not have any electrical connections to its hands or to the dial markings or numerals. Instead, the photoluminescent material of the hands and markings is rear-excited by "near ultraviolet" energy that is invisible to the observer. None of this exciting energy passes through the straw colored plastic clock face to reach the user. It would be harmless even if it did, but it would have a short-time, adverse effect on the user's dark adaptation.

Description

Figure 3 of the text shows the 22-watt, black-light, circline fluorescent lamp that supplies the photoexciting energy that passes through the molded glass (ultraviolet-transmitting) filter to form the visual background for the clock. Any replacement lamp must also be of the same (FC8T9 Black-Light) type but need not be of the same manufacture.

As indicated on circuit diagram, Figure 1-A, there are three luminance levels: Bright, Intermediate, and Dim, that may be selected through a 3-position toggle switch. The Bright position should be used for restarting after a power failure. Due to a peculiarity of the starting-dimming components and circuits of this clock, there may be several minutes delay in lamp restarting after a power failure, particularly if the clock is at the temperature associated with Bright operation.

Power Supply

This clock has been designed for 120-volt, 60-cycle operation. It is provided with a 3-conductor power cord and grounded attachment plug. The ground (red) conductor is connected to the metal enclosure of the clock.

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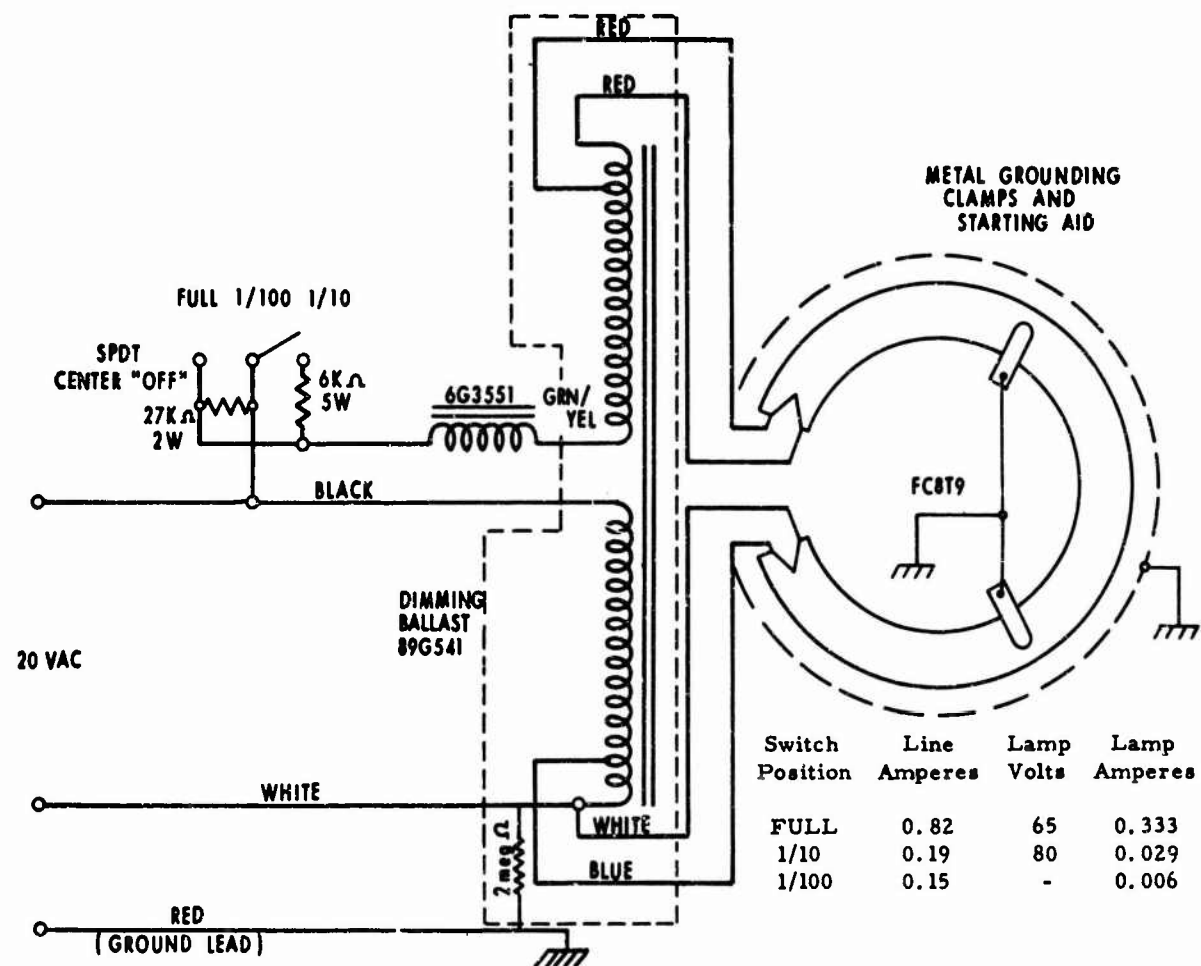


Figure 1-A

Black-Field Clock Wiring Diagram

Mounting

The clock was designed to be mounted on welded studs, spacers, or stand-offs of sufficient projection from the bulkhead to provide a minimum of 3/4-inch clearance behind each (shock mounting) mounting lug. Insofar as possible the clock should be mounted where its plastic cover will give a minimum of reflected images of light fixtures or other glare sources. It should also be shielded as much as possible from direct light for its own internal illumination to be most effective.

Lamp Replacement

The FC8T9 black-light lamp of the clock should not need replacement for approximately 1 year, minimum. When it does become necessary, place the clock on a bench, face up, de-energize it and follow these instructions:

1. Remove hand-set knob after removing its set screw with 1/16-inch Allen wrench.
2. Remove locknut and clamping screw on the 13-inch-diameter clamping ring that surrounds the dial-crystal.
3. Carefully remove clamping ring by flexing one end outward until it is disengaged. Continue this progressive disengagement around the dial without overstressing and permanently deforming the ring.
4. Remove aluminum pressure ring and plastic dial-crystal, flat rubber gasket, and plastic packing ring around periphery of glass background filter.
5. Lift filter glass (while pushing in on hand-set rod) and remove from clock case. Power leads to clock motor are a quick-disconnect type and must be disconnected before the filter is entirely removed.
6. Remove nylon lacing cords at lamp supports and disengage line plug from old lamp. Secure new lamp in place with nylon or linen cord and insert lamp plug in lamp.
7. After checking that new lamp will start, de-energize clock and reassemble.

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8. Upon reinstallation of clock at point of use, make sure that friction of watertight packing around the hand-set shaft does not cause reset gears to remain engaged. Hour and minute hands will not function unless reset knob is fully withdrawn after the reset operation even though second hand does rotate.

Cleaning

The plastic dial window may be cleaned with any mild solvent, non-abrasive cleaner known to be safe for Plexiglas or other acrylic plastic surfaces. One very satisfactory product is Pittsburg Plate Glass Company's "Silicone Glass and Mirror Cleaner," that also contains an antistatic to prevent attraction of dust.

Security Classification Unclassified	
DOCUMENT CONTROL DATA - R & D	
<small>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</small>	
1. ORIGINATING ACTIVITY (Corporate author) U. S. Marine Engineering Laboratory Annapolis, Maryland	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP
3. REPORT TITLE A Black-Field Illuminated Shipboard Clock	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) MEL Research and Development Report 391/66	
5. AUTHOR(S) (First name, middle initial, last name) Hardesty, G. K. C. , McLane, J. T., and Romoser, N. W.	
6. REPORT DATE March 1967	7a. TOTAL NO. OF PAGES 15
	7b. NO. OF REFS 5
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 391/66
b. PROJECT NO. S-F013-09 01	
c. Task 4982	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) Assignment 62 104
d.	
10. DISTRIBUTION STATEMENT Distribution of this document is unlimited.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY NAVSEC
13. ABSTRACT <p>An illuminated, bulkhead-mounting, clock has been developed that has outstanding conspicuity in the low-level luminous environments of combat information centers and darkened radar and sonar spaces. This development applies the "Black-Field" (photoluminescent) illumination technique to effect a unique presentation of hour, minute, and sweep-second hands as well as graduations and numerals in high contrast against a virtually "black" background. Although the lamp that feeds the optical system is in line-of-sight, it cannot be seen. The dial is of the "see thru" type and consists of numerals and graduations processed on the inner surface of the black-light absorbing "dial-window." The design features of the initial lot of preprototype clocks are described. The applicability of this technique to the illumination of other military displays is noted and it is recommended that a program be undertaken to develop near ultraviolet transmitting (almost visually opaque) plastic filters to replace glass where structural or manufacturing considerations make its use undesirable.</p> <p style="text-align: right;">(authors)</p>	

Security Classification

Unclassified

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
visual displays optics instrument illumination clocks Black-Field illumination ultraviolet lighting photoluminescent displays						

Unclassified

Security Classification